Proceedings of the Iowa Academy of Science

Volume 74 | Annual Issue Article 26

1967

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Recommended Citation

Lohnes, R. A. and Joshi, R. C. (1967) "Quantitative Variations in Loess Topography," *Proceedings of the Iowa Academy of Science, 74(1),* 160-167.
Available at: https://scholarworks.uni.edu/pias/vol74/iss1/26

Quantitative Variations in Loess Topography

R. A. LOHNES AND R. C. JOSHI[1]

Abstract. Morphometric studies were conducted on the "loess mantled" and "loess depositional" topographies of the Wisconsin Age loess of western Iowa. Slope angle and absolute drainage density decrease with increasing distance from the Missouri River as a power function. The rate of decrease of both parameters is great for the first 8 miles from the river and less for the next 24 miles. Although the change between the two types of topography is gradual, it is suggested that the transition from rapid to more gentle decrease of slope angle or drainage density with distance from the river be used as a quantitative criterion for the boundary between the two topographies. Relationships exist between loess thickness and absolute drainage density and slope angle which permit estimation of loess thickness from a measurement of these topographic parameters. It is suggested that measurements of this type will provide a remote sensing technique for the quantitative evaluation of other loess properties.

Western Iowa is covered with Wisconsin age (Ruhe, 1954) loess which thins from over 100 feet thick along the Missouri River bluffs to less than 10 feet in south-central Iowa. The thinning trend to the east and the attendant increase in clay content and decrease in particle size has been the subject of several systematic studies. Hutton (1948) studied the property variation in relation to pedogenesis and Ruhe's (1954) more detailed research resulted in a relationship between distance from the river and loess thickness expressed as a power function. The variation in engineering properties of the loess has also been studied (Dahl *et al*, 1958 and Hansen *et al*, 1959).

These quantitative studies have dealt with stratigraphic or petrographic aspects of the loess, whereas the descriptions of the topographic variations associated with the loess distribution are older and completely qualitative. The lack of quantitative data on the loess topography has probably been due largely to the paucity of accurate large scale topographic maps in the area.

The purposes of this investigation are to quantitatively describe landscape which classically has been called loess-depositional and loess-mantled topography (Kay and Apfel, 1928) and to suggest quantitative criteria for distinguishing the two types of topography. A third goal is to establish a relationship for predicting the loess thickness from topographic measurements.

Kay (1943) described the three to twenty miles wide strip of landscape adjacent to the Missouri River extending from Woodbury County to Fremont County in western Iowa as loess depositional topography, characterized by steep valley walls cut by gullies and sharp interstream divides.

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The loess in this area is from 60 to 116 feet thick. Immediately east is a region, 40 miles wide at the maximum in Crawford County, of asymmetric, more gently sloping hills. The loess cover varies from 30 feet thick on hilltops thinning to less than 10 feet on the hill slopes. This area is referred to as loess mantled topography. These two topographic areas have been mapped somewhat arbitrarily (Kay and Apfel, 1928) and are shown in Fig. 1.

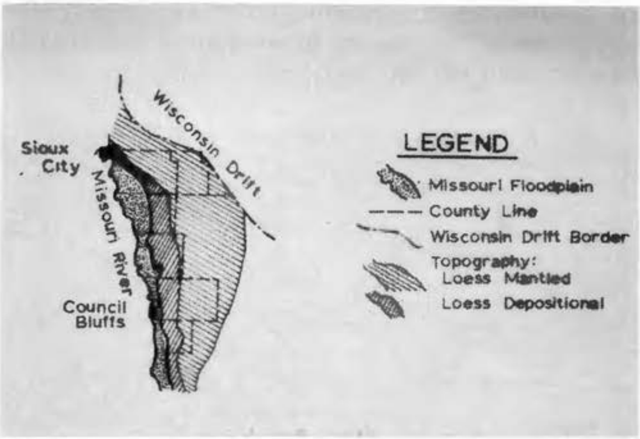

Figure 1. Loess mantled and loess depositional topographies as mapped by Kay and Apfel (1928).

MORPHOMETRY OF IOWA LOESS TOPOGRAPHY

U. S. Geological Survey 1:24,000 scale topographic maps are available for most of Fremont, Mills, and Pottawattamie counties. However, the maps in Pottawattamie County extend farthest east and permit the most detailed study of the variation in topography. The 1:24,000 quadrangles used in this study comprise two tiers of maps. In the northern tier from west to east are Loveland, Honey Creek, Underwood, Neola, Avoca N.W., and Avoca quadrangles. The southern tier consists of Council Bluffs North, McClelland, Taylor, Oakland, and Avoca S. E. quadrangles.

Valley side slopes were measured at every section corner across the series of quadrangles. The measurement was made by determining the height in a 100 foot horizontal distance along the steepest side slope segment nearest the section corner. The slopes along the north-south lines were averaged and plotted against the distance east from the Missouri River and are shown in Fig. 2a. Distances referred to with respect to the river are actually measured from the bluff line. These same data on log-log paper result in a linear relationship which when fitted by inspection gives the equation $S = 22.6D^{-0.28}$ where S is the slope angle and D is the distance from the Missouri River.

Absolute drainage density is here defined as the length of streams per unit area determined by measuring the total length of streams in an arbitrarily selected sample area of regular geometric shape. This measurement was performed by selecting square sample areas along the 41°20' latitude. Absolute drainage density versus distance east from the Missouri is shown in Fig. 2b. The equation for this relationship is $Ad = 29.9D^{-0.37}$ where Ad is absolute drainage density in one square mile, and D is the distance east from the Missouri River.

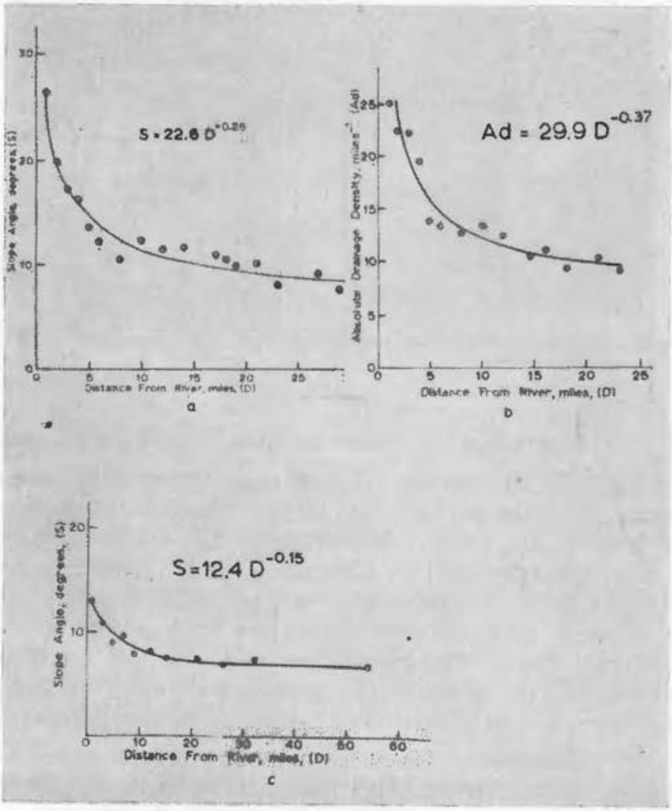

Figure 2. (a) Relationship between slope angle as measured on 1:24,000 topographic maps and distance from Missouri River.
(b) Relationships between absolute drainage density as measured on 1:24,000 topographic maps and distance from Missouri River.
(c) Relationship between slope angle as measured on 1:250,000 topographic maps and distance from Missouri River.

Maximum relief within the 0.25 square mile sample drainage areas was also measured but no systematic relationship is apparent. The maximum relief ranged from 90 feet about 16 miles from the river to 220 feet 1.25 miles from the river.

To describe the regional topographic variations, slope angles were measured on the Omaha, Sioux City, and Fort Dodge 1:250,000 scale topographic maps. As expected, the slope angles were less steep than the measurements on the larger scale maps. However, the relation of slope angles to distance is also a power function: $S = 12.4D^{-0.15}$. The graph is shown on Fig. 2c.

The scatter in all the morphometric data is the result of major tributaries to the Missouri such as the Boyer and Nishnabotna Rivers cutting across the study area. Adjacent to the tributaries there is a greater dissection which increases individual slope and absolute drainage density measurements but the regional trend is not obscured. The variation in slope angles is shown on the map in Fig. 3 and is similar to the variations in loess thickness and clay content (Hansen *et al,* 1959 pp. 317-318).

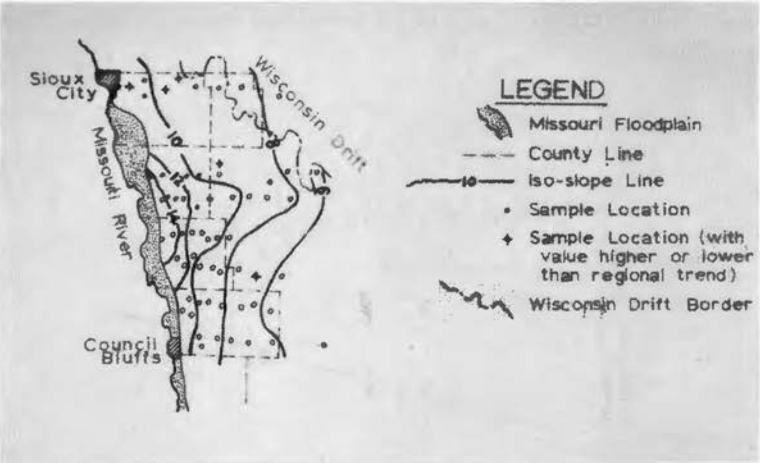

Figure 3. Map of slope angle trends in western Iowa.

On all three graphs (Figs. 2a, 2b, and 2c) the slope of the curve is steep near the river and decreases rapidly to about 8 miles from the river. This decrease in the rate of change in the parameters with distance provides a quantitative criterion for the distinction between loess depositional and loess mantled topography. The general trend of the curve relating slope angle to distance is not influenced by map scale, and the transition from rapid to slow change in slope comes at approximately the same distance from the river on both scale maps as seen by comparing Figs. 2a and 2c.

RELATION OF SLOPE TO EROSION

Although the deposition of the loess and its properties has influenced the erosional processes, the landscape is primarily a product of erosion and mass movement. Several workers have pointed out that most hillslopes would not exist without erosion of the landscape by streams. The obvious exceptions are depositional and tectonic forms such as sand dunes and fault scarps (Schumm, 1966).

Handy *et al* (1966) provided evidence that the steep loess slopes of the Missouri River bluffs are primarily controlled by mass movement. The general relationship between side slope angles and fluvial erosional features is illustrated by the work of Strahler (1950) who arrived at a rational equation, relating slope angle, S, to maximum relief, H, in a drainage basin, and drainage density D_d: $\tan S = 2HD_d$. This equation is based upon the conclusion that the average distance between stream channels is one-half the reciprocal of drainage density. Drainage density as used by Strahler is the total length of streams divided by the area of the drainage basin of an integrated stream system (Horton, 1945).

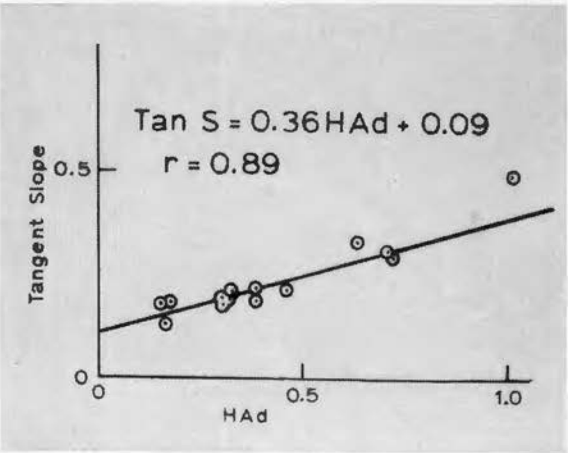

Figure 4. Relationship between tangent of slope angle and the maximum relief times the absolute drainage density.

The absolute drainage density used in this study may include parts of several integrated nets since the stream lengths are measured within a randomly selected area of arbitrary size. Although these parameters will not fit the rational equation of Strahler, a linear relation between HAd and S is given by the empirical equation $\tan S = 0.39HAd + 0.09$. A correlation coefficient of 0.89 indicates that the correlation is significant at the

1% confidence level. This relationship is shown in Fig. 4 and extends throughout both loess depositional and loess mantled areas.

A further relationship between fluvial erosional forms and valley wall slopes is seen in Fig. 5, where a linear relationship exists between stream gradient, G, and slope, S, according to the equation $S = 1.81 + 0.41$ with a correlation coefficient of 0.59. This correlation also is significant at the 1% level.

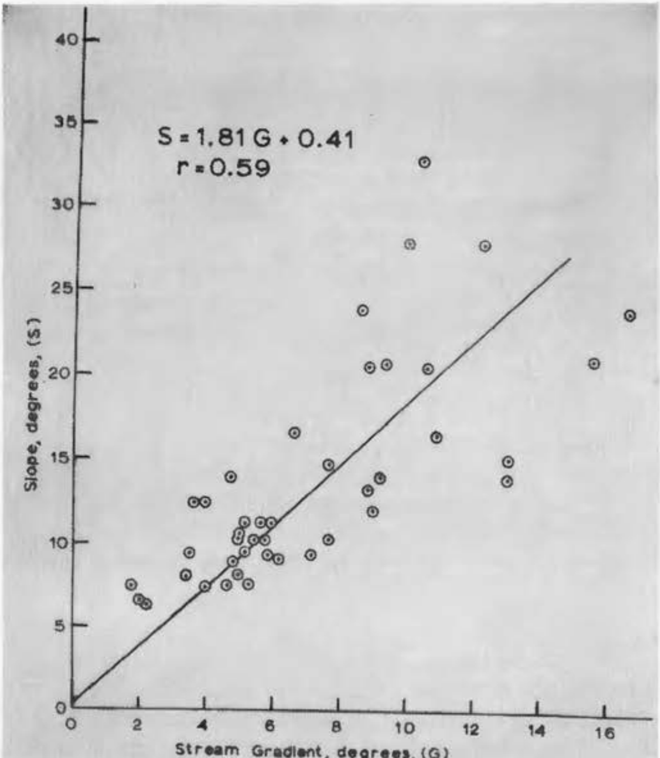

Figure 5. Relationship between slope angle and stream gradient.

These correlations between slope angles and fluvial erosional forms suggest that the term "loess depositional topography" is inappriate because it places too much emphasis on the landscape in that region as a depositional form.

Prediction of Loess Thickness

Similarity of trends in topography to regional trends of loess properties and thickness are evidence for the possibility of quantitatively evaluating properties of the sediment by measurements of the landscape. Figure 6 shows the empirical relationship between absolute drainage density and loess thickness and also between slope and loess thickness. By measuring either of these landscape parameters on 1:250,000 topographic maps, one can predict the thickness of the loess from Fig. 6. The precision and accuracy of this remote sensing technique are yet to be field checked. Although scale will influence the value of morphometric parameters obtained from air photos or larger scale maps, it appears that similar empirical relationships can be established for predicting loess thickness and other properties.

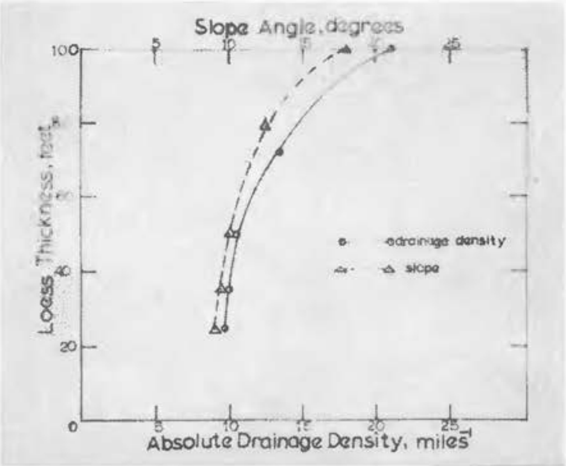

Figure 6. Empirical curves for estimating loess thickness from measurements on 1:250,000 topographic maps.

CONCLUSIONS

Both absolute drainage density and maximum slope angle can be related to distance east from the Missouri River as power functions. The relationship of distance to slope angle is different from large to small scale maps due to accuracy of mapping and measurement, but the general form of the equation in each case is the same. The quantitative criterion for the transition from loess depositional to loess mantled topography should be on the basis of the transition from rapid to gentle rate of change in slope angle or absolute drainage density with respect to distance. The topography in the entire study area is controlled by fluvial erosion as evidenced by the linear correlation of slope angles to absolute drainage density and stream gradient. It is possible to estimate loess thickness from measurements of absolute drainage density and slope angle on 1:250,000 maps.

ACKNOWLEDGMENTS

This paper is Technical Report 6 of the Office of Naval Research project number NR 389-144, contract number Nonr 4868(01) and contribution No. 67-5 of the Soil Research Laboratory, Engineering Research Institute at Iowa State University.

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